The Miracle Array

The impasse provided an important moment for Los Alamos' Todd Haines. When still a graduate student at the University of California, Irvine, Haines had begun working on a new approach to detecting gamma-ray showers—an approach involving water.

Shower particles that intercepted a huge tank of water would streak through the water at nearly the speed of light, setting electrons in the water in motion. Those electrons would radiate light, and because light has only two-thirds its normal speed when going through water, the light would trail behind the speeding particle and form a wide-angle (41-degree) wake, like the bow wave formed by a boat traveling faster than the speed of water waves or like a supersonic plane's shock wave, which creates the sonic boom. Any light detector within the wake would detect the shower particle.

Now, if an array of hundreds of light detectors (photomultiplier tubes, or PMTs) were immersed in a mammoth tank, an arrangement could be found that guaranteed that light from every particle entering the pond would be detected. In addition, the array could operate during the day if covered with a light-tight tent that kept out every ray of sunshine.

The idea was very promising, but with no funds to construct the water tank, it was just another new idea. Then one day Darragh Nagle, a Los Alamos nuclear physicist, burst into Haines' office and announced, "I know where we can build your project."

Nagle took Haines to Fenton Hill in the Jemez mountains west of Los Alamos. There an abandoned manmade pond, once used as a holding tank for an experimental geothermal well, now stood ready for another purpose.

Thus began Milagro (Spanish for "miracle"), in which a small pond was transformed into a new window on the universe, one that would view the most-extreme phenomena in our galaxy and regions nearby.

The Fenton Hill pond was 195 feet by 260 feet and 26 feet deep. It was smaller than desired but could be supplemented by small water tanks outside the pond—outriggers—each containing a PMT. The outriggers would be spaced over an area 10 times the size of the pond. For showers that intercepted the pond only partially, those outriggers would detect the central core of a shower, thereby enabling accurate reconstruction of the shower direction.

"The outriggers increased Milagro's sensitivity by a factor of two, and that made all the difference. We went from barely seeing the Crab Nebula, the brightest gamma-ray source in the northern sky, to discovering new sources of TeV gamma rays in our galaxy and finding a path towards proving that certain sources are cosmic-ray sources," says Sinnis.

How Milagro Worked

At an instant in time, an air shower looks like a pancake of high-energy particles descending toward Earth along the direction of the initiating gamma ray or cosmic ray. The particle density is highest at the center of the pancake (the shower's core) and decreases with distance from the core.

Milagro determined the direction of the shower by recording the time of arrival of the different particles in the shower. In the figure at right, the tops of the red lines represent those arrival times. Those tops define a plane parallel to the plane of the shower (white dots), and the shower direction is perpendicular to that plane.

The greater the energy of a shower, the larger its area. Therefore, the energy of the shower can be estimated by counting the number of light detectors (PMTs) that give a signal. It's a rough measure but capable of distinguishing showers within Milagro's broad range of sensitivity, from 0.1 to 100 TeV.

HAWC, the planned successor to Milagro, will have a much-larger area and higher altitude and therefore get a much more accurate measure of the energy.